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X-RAY KYMOGRAPHIC STUDIES OF THE CENTRAL CIRCULATORY ORGANS DURING THERAPEUTIC BATHS AND DURING HYDROSTATIC PRESSURE INCREASE. THEIR TECHNIQUE, RESULTS AND DEVELOPMENTAL POSSIBILITIES

A SURVEY ARTICLE

Friedrich Ekert

Translation of: "Roentgenkymographische Untersuchungen der Zentralen Kreislauforgane Waehrend Therapeutischer Baeder und bei Hydrostatischer Druckerhoehung. Ihre Technik, Ergebnisse und Entwicklungsmoeglichkeiten," *Arkhiv Fuer Physikalische Therapie*, Vol. 6, pp. 66-82, 1956.

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16. Abstract

Experiments performed in the late 1930's are recounted by the author. His studies involved the use of bathtubs of various shapes, ranging from shallow flat ones to tall structures the height of a man, in which subjects and patients were subjected to x-ray kymography. The changes in the size and function of the heart and lungs were recorded and studied. It is suggested that modern equipment would make such studies even more rewarding today.

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A SURVEY ARTICLE

Friedrich Ekert[1]

In studying the work of Hauffe, in which reduction of the heart shadow silhouette as detected on the fluorescent screen was mentioned in Hauffe rising arm baths, the author of the present paper came to the conclusion in the early 1930's that he should check these findings with the more accurate methods of a large x-ray and physical therapy department, such as was available to him as the chief physician of the former Rieder Institute. At the same time, however, the data of Hauffe not confirmed by x-rays, concerning the more disadvantageous effect of the total bath on the central circulatory organs, should be subjected to x-ray examination. /66*

The studies performed in this connection in Hauffe rising partial baths posed no difficulties, since the x-ray kymography of the heart developed at the institute using the Stumpf method and the x-ray kymographic apparatus built by Stumpf could be used. The data of Hauffe were largely confirmed (Epple).

The solution of the second task was much less simple, namely, monitoring the behavior of heart size during total baths by means of x-rays; the feasibility of such a study was generally initially denied in 1934 by experts. The fact that a person so learned in the field of x-ray techniques as Groedel, who had built apparatus for direct x-ray kinematography and who was at the same time very interested in balneotherapy, had devoted a single section in his textbook of x-ray techniques to discussing the dilation of the heart in full baths but failed to mention any x-ray methods for doing this, indicates that he initially was not impressed. Now, however, since 1932 we have been generally using a /67
patient-protecting 4 mm aluminum filter for fluoroscopy of the stomach, a

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*Numbers in the margin indicate foreign pagination.

technical modification which goes back to W. Frik in 1926. We therefore knew from our own experience that despite all expectations, 4 mm of aluminum had scarcely any influence when x-rays were used at higher voltages. We therefore had the back wall of a galvanized bathtub replaced by 2 mm of aluminum and used the remaining aluminum layer of 2 mm for further arrangements planned later on. In the course of the development of these devices, the author and his associates succeeded after long years of work in obtaining satisfactory x-ray pictures of the heart even during all manner of therapeutic full baths, and in 1939, together with Willbold, were able to incorporate x-ray kinematography into the research system; this was clearly an advance, but could no longer be exploited due to destruction of all the apparatus in the war. The author and his associates did manage to shed some light on various problems concerning circulation and the effects produced by full baths, as will be shown in the following; since the development of x-ray technology in recent years through the manufacture of very voltage-resistant rotary anode tubes has considerably simplified and improved the applicability of the method, of which only portions have been published, they would like to disclose *in toto* to a wider circle of persons. This is especially true since the systematic study of hydrostatic effects in the positive and negative sense doubtlessly constitutes a very practically important task for balneotherapeutic research; at the present stage of x-ray technique, such work can also be carried at the research institutes of spas for circulatory diseases and can therefore establish a new line of activity which could be of interest to other types of resorts as well. For example, there are probably many applications in circulatory physiology, roentgenology, experimental pharmacology and so forth that can develop from this topic.

The present studies are deliberately limited to the roentgenologically comprehensive effects of hydrostatic pressure and the central circulatory organs. The problems involved on the physiological side and the development thus far of corresponding views, which were subject to many erroneous approaches, will be discussed herein in a professional manner by Mr. Stigler, who has had the responsibility of working for many years (since 1911) on an experimental basis in this area.

1. Apparatus for Balneological X-ray Kymographic and X-ray Cinematographic Studies

After several orientational tests with primitive wooden troughs in 1935, the large balneokymographic full bath apparatus with its supplementary attachments for studies in CO_2-baths and mud baths was put into use, consisting of a special tub with an aluminum back, the aluminum submersible box for the kymograph and fluorescent screen, lifting equipment and various supplementary devices (Figure 1a-c).

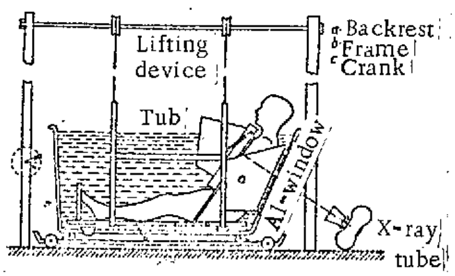


Figure 1a. The Device in the Kymogram Recording Position. Clearly visible are the waterproof box for the kymograph, the lifting frame for the patient, the aluminum on the back of the tub, and the carriage for the tub. The first design in a photo by Ekert, *Balneologe*, Vol. 5, 1938.

In order to be able to follow heart action and heart size in ordinary or therapeutic full baths, there were five requirements that had to be satisfied first: /68

1. The picture must be capable of being taken through the back of the tub; this is simply achieved by installing an aluminum window 1.0-2.0 mm thick in that location. It was necessary, however, to take into account the various slope angles of this back wall, since the thorax had to rest against the aluminum plate so that the x-ray beam would not have to pass through a considerable layer of water. Therefore, various fixed slope angles of the tub back were used: first a steeply vertical back wall (steep bath), then a slightly sloping normal type and finally an extremely flat type, referred to for short as the flat tub, all of which could be mounted on the same stand. The individual tub shapes are described by Anstett, with respect to their physiological and historic significance as well.

2. It was also possible that tilting the body at the waist might not be completely indifferent as far as blood distribution or stagnation is concerned, at least for certain types of constitutions, as was later found from quite different tests by Korb on the influence of position on the degree of attainable shortwave hyperthermia in the lower abdomen. Hence, long tubs had to be used.

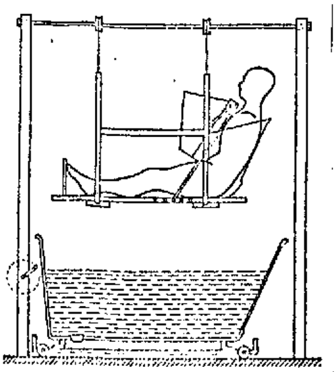


Figure 1b. The Device When the Bath Medium is Being Changed. The maintenance of the same position is ensured by clamps to hold the patient in place while being raised on the lifting structure; the backrest is made of aluminum for the sake of transparency to radiation.

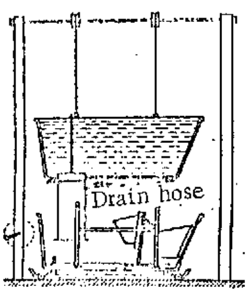


Figure 1c. Additional Mechanism for the Device: Premixed Mud Bath, to Allow a Very Rapid Influx of Liquid Mud Prepared in Advance.

3. The kymograph, the mechanism for making the x-ray kymograms, had to be capable of being submerged in water without being damaged by moisture. The kymograph also had to be easily accessible for changing cassettes and had to be fixed in place; in addition, it must not disturb the median position of the head.

4. The entire system for keeping the kymograph watertight had to rest against the anterior wall of the thorax in the tub without impeding respiration. /69

5. The correctness of the adjustment had to be checked using a fluorescent screen.

As the optimum shape for this design, we selected an aluminum tub with a broad space at the front for convenient accommodation of the fluorescent screen, with a kymograph box having a thinner aluminum plate 0.5 mm thick on the side against the thorax, in order not to incur excessive x-radiation losses. The portion of the submersible box next to the thorax contains the actual container for the kymograph, which had a large opening toward the foot end in order to allow rapid changing of cassettes. The larger part toward the foot end served to accept a removably mounted fluorescent screen and possibly a mirror to facilitate observation of the fluorescent screen.

The problem of adjusting this submersible box to fit the size of the subject and his position was handled by mounting feet on it, installing rods with holes on them on both sides, and providing guide tracks with fastening screws to adjust the tilt angle.

As the experiments proceeded, it proved necessary to keep the subject in a precisely fixed position without his own movement and to lift him out of the water in this fashion, then lower him again, for example for comparative tests involving different bath water temperatures. The tub was equipped with a stretcher and a lifting device, making it possible to lift the stretcher, together with the subject and the kymograph, out of the tub by means of a crank drive. An additional stiffened backrest 0.5-1.0 mm thick had to be provided to lend some degree of stability; made of aluminum, it fitted exactly against the aluminum back of the tub when the subject was lowered.

Later, it also proved advantageous to equip the back of the lifting frame in its lower part with a galvanized iron pan to make a more comfortable seat. In addition, a footrest and several wide safety belts were provided, since it was found that when lowering a subject into a full tub it was easy for changes in body position to result from the movement. After the original test recordings have been made in the empty tub, the lifting device was also used to make preparations in the latter without the subject, e.g., CO_2-baths, hydrostatically heavy salt baths and so forth.

Since any reduction of scattered radiation contributes to improvement of x-ray image quality, the radiation inlet window of the tub was later reduced in size by adding lead, leaving only the necessary amount open, and the sides of the tub were lined with lead foil 0.5 mm thick, using a watertight coating due to some lack of permanence with respect to bath preparation solutions.

The rear wall of the balneokymographic lifting device was constructed in such a way that the tub could be wheeled in and out on a carriage for installation on and removal from the lifting frame; this was found to be very advantageous.

The height of the apparatus, 2.20 meters, was limited only by the height of the door of the x-ray diagnostic room, and could have been made higher if a choice had been possible; a greater width would also have been advantageous, but was out of the question for the same reason. Greater height would also have made it possible to use higher tub carriages; this would have considerably facilitated the recording technique.

On the other hand, it was even more difficult to design a tub which would allow tests in an extremely flat body position (flat tub tests): a balneoroentgenokymographic flat tub apparatus (Figure 2). This design was not easy to achieve because the apparatus had to be built in such a way that despite the flat position and the low water level, the thorax (even on its ventral side, in other words, uppermost in this case) would have to be covered by water and this /70 would only be possible for slender individuals; it was also necessary to have the flat tub sufficiently high that the x-ray tube could be placed the necessary distance beneath the tub. The result was necessarily a very tall apparatus.

Another, much easier way to achieve this solution would have been to install the x-ray apparatus on the story below, a construction principle that was out of the question in 1942.

The balneoroentgenokymographic flat tub apparatus was also designed for other purposes, such as the previously unattempted study of the gall bladder under balneotherapeutic application, for example for observing gall bladder function under massive hydrothermal effects; for this purpose it was necessary to replace the aluminum window. It could also be used for studies of the behavior of the spleen in cold and hot baths, on which there was only information from animal experiments.

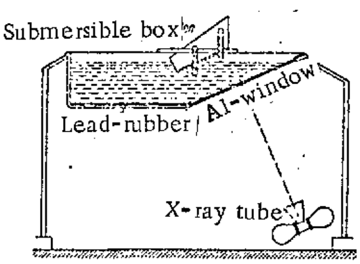


Figure 2. Flat Tub Apparatus in Rough Schematic Form. Photograph from Anstett, *Balneologe*, Vol. 10, 1943.

To check the conditions with a significant increase in pressure, the x-ray apparatus was built into a standing bath container the height of a man (balneokymographic standing bath apparatus), which offered no particular difficulties in its primitive form (Figure 3). Complicated arrangements were necessary if rapid filling and emptying of this standing bath container were to be feasible, and these were tests which we could no longer carry out. They would have required the construction of a water reservoir. One of our standing bath devices was combined with an apparatus for infrared photography of the leg veins.

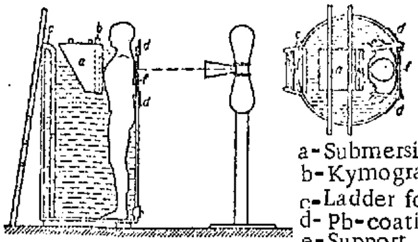


Figure 3. Standing Bath Container the Height of a Man, with a Tub for the Kymograph. The drain opening was made much larger in a later design.

Finally, it was necessary to study pure cold-water and hot-water effects without simultaneous hydrostatic pressure on the body, in other words, the x-ray-kymographically perceptible reaction to showers and so forth. In this case it was necessary to protect the kymograph completely against moisture and simultaneously mount it so that it could be tilted in any direction on a stand, in such a way that it could be moved around but could also be locked so that the defensive reflex reactions of the subject would not lead to a /71
displacement or change of position. This goal was achieved by a protective wall of plexiglas in front of the kymograph, mounted on a very stable stand, and the kymograph itself could be tilted and locked within the required range (x-ray kymographic cold-shower apparatus). This device was destroyed in the war following a series of tests. Mention has been made of why the x-ray kymographic method according to Stumpf, particularly its flat kymographic form, was chosen. The studies were initially performed with heart closeup pictures, in order to determine the general utility of the x-ray dipping or sinking method. In addition to the disadvantages of the closeup picture which even in the x-ray kymographic method we chose had been necessarily encountered until recently, namely, the more pronounced indication of more distant parts of the heart and the more significant size inaccuracy, as well as a slight fogging of the pictures caused by the scattering effect of the water and metal masses, which made the evaluation of the pictures very difficult. Moreover, it was highly unclear whether a particular heart phase was picked up, if one did not irradiate for a long period of time, and thus obtained a definitely diastolic basic form with considerable lack of sharpness in the contour. The various switching mechanisms, i.e., with the aid of the R peak of the EKG (described in Groedel) were not involved in the present studies. The method with simple heart pictures would have had only one advantage, namely, the slightly reduced radiation exposure of the subjects. This radiation exposure in the method of

x-ray kymography which was finally chosen, as will be shown later on, was within limits that were completely representative and were in no way in excess of ordinary values.

Stumpf x-ray kymography also allows simultaneous recording of the so-called systolic and diastolic heart size and heart shape, with some limitations, and the method was therefore much superior to simple heart recordings and also gave pictures much more rich in contrast, since the kymograph raster has a definite wavy effect. The concepts of systolic and diastolic are not to be taken strictly in their physiological meanings in this context, since the x-ray kymographic heart shadow picture, as Heckmann was the first to point out systematically and experimentally years ago, is not a pure heart pulsation picture but sums the pulsating movements together with other heart movements (pendular movements [Heckmann, Ekert et al.], rotation with the weather-flag shadow phenomenon of an asymmetric body with eccentric axis of rotation [Ekert], lifting motions and so forth).

X-ray kymography according to Stumpf, which is the first practically feasible embodiment of a method known in principle since 1912 (Sabat), and which is also very much used for clinical purposes, uses a metal plate which is not transparent to x-radiation but has a number of parallel slits running diagonally across it, passes through an area during the x-ray exposure (about 2-3 seconds) which is somewhat smaller than the distance of the slits. By this arrangement only a relatively short distance is available for the travel of the slit, since otherwise the "travel fields" of the slits and hence the corresponding exposure blackenings would overlap; this means that only a few small marginal movements of the heart can be imaged if one does not want to run the danger of narrowing the marginal movement readings excessively in the cranio--caudal direction due to excessive compression of movements into a very small space and thus being unable to evaluate the differences except with difficulty, if at all. On the other hand, there is the great advantage that in contrast to single-slit x-ray kymography and x-ray kymography with several slits, as mentioned by Sabat, Zdansky, Cignolini et al., the heart can be examined and evaluated *in toto*, and that a synchronous comparison of the types of movements of the various heart segments is possible, which is a tremendously important advantage of the Stumpf method.

For the present studies, the flat kymogram which showed the heart shape without any omissions was more favorable than the step kymogram, in which (all other conditions being equal) the film moves and the raster plate stands still, /72 so that only the movement of the marginal points of the heart at the interval of the slits shows up. This has only had the advantage that the kymoscope was able to reproduce the heart movements taking place during the kymogram recording, admittedly somewhat pseudoreal.

Essentially, it was originally desired that x-ray kymography in a full bath should be carried out as a remote recording method at a distance of 2 meters, instead of 1 meter as proved necessary. This would have reduced certain aspects of the heart shape and shown the hilus ratios better, as we already mentioned in 1939 in a discussion of our balneokymographic method.

Such heart remote kymograms were not possible until 1950, however, using three anode tubes as a rule, because the latter could stand voltages only up to about 90 kV. The required 4-fold illumination intensity required when doubling the distance can only be achieved within the time frame of the heart kymogram by corresponding increases in the mA number or the voltage. The new oil-hood rotary anode tubes allow voltages up to 125 kV and therefore almost complete elimination of the required increase in illumination. If possible, apparatus and x-ray tubes will be used for balneokymographic studies which can handle voltages up to 125 kV. With respect to the kymograph model that can be used, we can state that the older types are more suitable for balneokymography than the new ones, with the exception of their use in devices with standing baths in which it is largely immaterial what type is used. In submersion boxes for bathtubs, only those models have been used which have a switch housing that is not too tall and may be mounted upside down. A tall switch housing in this inverted position obviously prevents the absolutely necessary placement of the chin, which best ensures the orthoroentgenograde position. The fluoroscopic installation which is mass-produced for new kymographic models cannot be used in the submersible box because the raster plate has to travel 40 cm laterally, and there is no space in the submersion box for this. A special model with simplified switch panel is still better than the old models.

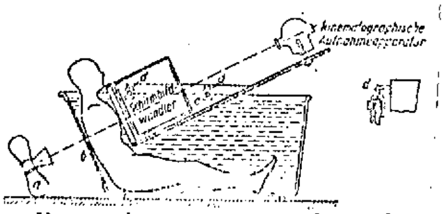
The balneokymograms give the size, shape and marginal movement pattern as well as the modifications in the latter only for a certain comparable diaphragm distance.

Under the hydrostatic effect of pressure, not only (as was shown in our experiment) do the type of filling and type of movement of the heart and the large vessels change, but also the type of breathing and the movement of the diaphragm; it seems desirable for further clarification of the critical questions of the interplay of these factors during respiration to determine simultaneously by means of x-rays the phases missing from the balneokymograms. We must also not forget to note that x-ray kymography never shows total movement but only the movement component in the direction of the raster slits. By diagonal and cross mounting of the kymograph one can analyze the other movement components as well, but not simultaneously, since it would be necessary to have very large submersible boxes and a multiplicity of kymogram pictures. After indirect x-ray cinematography of the heart, in other words the cinematographic recording of the x-ray fluorescent picture of the moving organ with a very bright cinematographic recording apparatus, had developed by 1938 to the extent that it was possible to use it for the chest organs in man (at least at short exposure times) /73
without excessive radiation injury, the author together with Willbold constructed the x-ray cinematographic submersible box apparatus (Figure 4) with which a number of test recordings were made: a sample from this experimental series was published in his time by Willbold. No systematic use of the apparatus was achieved. The apparatus was later destroyed in the war.

In studies of this kind, the relatively high radiation dose was harmful to the subjects, so that such recordings could only be made for a few seconds and the corresponding short film strips had to be put together for projection into an endless strip according to Torelli.

One answer to this might perhaps be avoiding using limited picture sequences, in other words, a procedure somewhere between series photography and cinematography, and is now used in series cardioangiography, etc., to a large extent.

In the meantime, the electron-optical image converter has been developed further; it amplifies the fluorescent screen about 800-1,000 times, in other words, at a low radiation dose it can provide bright fluorescent screen images and has already been used successfully for the setting of fractures, x-ray cinematography of the bulbus, and movements of the appendix in man (Janker). However, in addition to a certain granular lack of sharpness, it has the disadvantage of a relatively small image area, so that it is not yet suitable for taking pictures of the entire chest but only parts of it. If it becomes possible in the course of further developments to eliminate the disadvantage of the small field, a combination of the x-ray cinematographic submersible box apparatus with an image converter (Figure 4) would make it possible to take a picture of the entire chest and its organs during respiration, before and after the influence of therapeutic total baths or x-ray cinematography; experiments in this direction have not yet been undertaken.



a-X-ray tube
b-Al-window
c-Submersible box
d-Tracks
e-Movie camera
f-Fluorescent screen converter

Figure 4. Apparatus for X-ray Cinematography. The image converter, drawn in the form of a box, constitutes only a possibility for future development and has not yet been used.

2. Procedure Techniques

As required by balneokymographic recording techniques, illumination poses no great difficulty as long as kymogram recordings are involved; in general, it is merely necessary to work harder and provide more illumination.

If necessary, the studies can even be carried out with an (optional) portable half-wave apparatus, e.g., in the standing bath recordings which were linked to another room; as a rule, however, large apparatus was used (4-valve and 6-valve apparatus). /74

When taking such pictures under conditions of scattering by water and metal, careful screening is necessary, partly to eliminate overlapping of the image by a scattered radiation veil, which can come from numerous sources in the necessary experimental arrangement, and partly to protect the personnel (see Section 4).

A much more difficult procedure in conjunction with making kymograms in a bathtub is obtaining a position of the diaphragm which allows adequate comparison of the kymogram before filling the tub and with the tub full; in particular, respiration must be avoided which produces pronounced suction or pressure conditions in the chest (Mueller and Valsalva effects). After the diaphragm has been pushed upward under the influence of hydrostatic pressure on the abdomen, the initial recording prior to the action of the hydrostatic pressure should in no case be made with a deep inspiration. To the extent it is possible, a number of similar initial recordings are made with variations in the position of the diaphragm which resemble the expiration position more closely. If the subject is then allowed to inspire gently while in the bath, one will obtain a position of the diaphragm which is the same or at least approximately the same in the pictures, to the extent that a displacement of the gas filling the colon makes this completely impossible.

In order to evaluate any changes in the position of the chest, as was done in the course of the work, one can use small pieces of fine-mesh wire which are attached to the ventral or dorsal surfaces of the chest or both with adhesive. Wire screen is suitable for this purpose because it allows differences in inclination to be detected more readily. Unavoidable changes in the shape of the chest easily result on the one hand from the fact that even with 30 cm of water in a tub the thorax circumference decreases by 1-3 cm (Strassburger); on the other hand, as we have already mentioned, the type of respiration changes entirely, as well as the width of the lower aperture of the thorax.

In a standing bath the height of a man the water pressure is higher and the difficulty in achieving comparable positions of the diaphragm before and after filling is greater.

Kymogram recordings in a mud bath pose no greater difficulties from the x-ray technological standpoint than do those in a water bath.

As required by electrical techniques, we used hard settings (80-90 kV with a 3-phase apparatus of the type used in 1936) and would be able to use still higher voltages today. Such hard radiation mixtures are required to a much greater extent than was the case in our tests, in the interest of image contrast and edge-serration sharpness with very careful diaphragming and extensive scattered radiation shielding even outside the direct cone of rays. At excessive voltages, the pictures become fuzzy. With respect to the higher radiation danger to personnel when using high voltages (hard radiation techniques), the reader is referred to the next section (3).

In the course of correspondence with von Diringshofen, who dealt on the basis of other viewpoints with the problem of hydrostatic pressure in bath applications, a significant proposal was made that in such experiments the water level should be based on the hydrostatic level of the heart.

In the author's experience, aside from the usual questionnaires, it would be important to have an extensive recording of the type of constitution of the subject or patient in accordance with the following viewpoints:

1. Types of constitution according to Kretschmer, Lampert and Curry. A portion of this type classification refers to the tolerance of baths with cold or hot temperatures (they could be referred to as the sauna and Priessnitz types).

2. Determination of the balneophysiological daily rhythm. There are types who consider only ice-cold baths, never hot baths, tolerable in the morning and vice versa, but would find hot (or on the other hand, cold) baths to be extremely comfortable in the evening, all of which has to do with the vegetative reaction status. /75

3. Determination of the balneophysiological degree of training in a positive or negative direction, for the two temperature types. There is undoubtedly a great difference as to whether one would expect an athletic mountain climber or a nun, a member of a polar-bear club or a dedicated sauna bath fan to prefer cold or hot conditions.

4. Determination of the vasomotor type of constitution, especially the collabophilic types with a constitutional tendency toward orthostatic anemia of the heart, which shows up during fluoroscopy in the standing and reclining positions.

5. Determination of simultaneously active pharmacological components, e.g., nicotine, caffeine and so forth, which in the affirmative case also affect the problem of whether there is a particular sensitivity in this direction.

It is definite that the residual blood volume in the heart is significantly affected by the degree of peripheral circulation. Peripheral circulation, however, is influenced extensively by the action of nicotine, caffeine, alcohol and so forth. There are types who, according to the author's experience, exhibit sensitivity in this respect (as shown in heat radiation measurements) so high that the entry into the room of a third person who is smoking, which would not affect the results of the measurements in any way if there were no cigarettes present, is sufficient to change the heat radiation, and therefore probably peripheral blood flow as well.

6. Noticing certain factors of the degree of filling of the abdomen and water saturation of the body (mealtimes, intake of liquids and so forth).

7. Determination of the psychic and somatic reaction situation (vegetative dysthonia and so forth).

The peripheral vascular reaction (or, on the other hand, the psychic reaction status) influence each other, as indicated by experience.

It would also be advantageous to take weather factors into account as well and to note certain important components in the reports as well, such as the foehn.

3. Ensuring Radiation Protecting and Protection Against Electrical Accidents in Balneoroentgenological Studies

It is very important in such studies to ensure safety of radiation protection for kymogram series as well as for the subject or patient and the personnel. This does not apply to individual kymograms, but kymogram series, which are being performed on a given subject and in an environment composed of water and masses of metal which considerably scatter the radiation.

The personnel are endangered somewhat more by radiation in balneokymographic studies than in regular x-ray operations. Most balneokymograms are taken near the floor and require coming closer to the experimental apparatus, even during exposure, than is the case in other studies.

Still more important is the radiation protection for simple x-ray cinematographic studies, i.e., without an image converter. Here the permissible dose for the subject is reached in the course of a few seconds and longer studies (in other words, taking longer strips) is not possible at all. In patients and in angiocardiography, in which a vital indication is given, e.g., the decision for a heart operation involving congenital defects, the conditions are more favorable if the milder x-ray damage that occurs were to be evaluated quite differently from the legal standpoint than would be the case for a subject.

When using the image converter for x-ray cinematography, such studies are practically safe within certain limits; thus, for example, using the image converter, bulbus movements, the function of the appendix and so forth can be detected by means of cinematography without any danger; these are objects which are much less easily accessible than the heart.

As the permissible surface dose for the subject or patient, 100 r per day /76 is used in such experiments, while a higher dose is permissible when the tests are distributed over several days; these doses can be calculated approximately using the Holthusen data. After such an exposure, however, that particular subject should not receive any additional doses for the next six weeks unless absolutely necessary. In addition, the 100 r, even when the phase of interruption is observed, should not be repeated with arbitrary frequency.

This permissible skin exposure for patients or subjects has been carefully selected; skin reactions, such as erythema, should only show up when levels four times this are used. The dose of 100 r will probably be received frequently in mud passages, and will often be exceeded. It is obvious that as a rule, in contrast to fluoroscopy of the chest and x-rays of the chest, as well as kymogram and x-ray cinematogramic pictures of the thorax, with a closely diaphragmed and movable radiation beam is used, and so a rather small radiation field wanders to and fro.

Since the data on r refer to radiation absorption in cm^3, the volume dose, which can be given in r/liter, at the same r number and large incident field, is naturally very much greater than for a small incident field; the volume dose, however, for which there are no current data on the permissible value, is critical for the general reaction of the subjects to x-ray effects, while the $r/^0$ dose is a measure of the skin exposure and indicates the local skin reaction to be anticipated. According to the definitions, therefore, even at relatively low, locally absolutely harmless x-ray doses and high-volume doses, under certain conditions even general reactions will appear, e.g., radiation aftereffects, if the body volume through which the radiation passes is relatively too large. We have never seen such reactions in our numerous, albeit careful, balneokymographic tests and also in the admittedly few balneocinematographic test.

According to our previous measurements, which refer to radiation qualities up to 90 kV, the surface dose on the dorsal skin of the subject with a total filtration of approximately 3.5 mm aluminum, of which 1 mm was in front of the tube window and 2 mm consisted of the aluminum back or back wall of the tub, approximately 1-2 r/kymogram, in other words no more than was given by Neef in 1936; the higher load was probably balanced by the higher protective filtration. Theoretically, therefore, approximately 50 kymograms would have been permissible. Due to the role of the volume dose and for reasons of skepticism with regard to the difficult radiation dose measurements, we never went beyond 15 kymograms per case under these conditions; even this number was not reached as a rule. It should be mentioned that recently Wachsmann gave very much higher radiation doses for simple kymograms (10-12 r). The best thing would then be to have the incident r-dose per kymogram determined by a dosimetry expert prior to the beginning of the experiment.

The radiation protection for fluoroscopy in the submersible boxes of the balneokymographic apparatus is much more difficult to ensure than in kymogram series. Such fluoroscopy is generally not recommended. Under the conditions which we described, the highly filtered areas in the tub were assumed during fluoroscopy to receive a dose of about 4 r/minute, while the neck and head were completely covered.

Particular emphasis should be placed in fluoroscopy using balneokymographs that these head and neck areas of the subject, if diaphragming is absent, can receive a higher radiation dose, approximately twice that desired, because here the aluminum layer of the tub window and the back wall of the lifting frame are absent; the latter have the same effect as stronger aluminum protective filtration. It is possible to do away easily with this completely superfluous exposure to the skin by careful narrowing of the fluoroscopic screen through the so-called deep diaphragm, use of suitable tubes and so forth, or by an additional lead plate 2 mm thick.

Another source of danger in fluoroscopy consists in the fact that the doctor or personnel can easily come directly into the direct beam of radiation, since the radiation is near the ground and it is possible to approach the x-ray tube window inadvertently, while this is not possible at all in regular fluoroscopic devices such as stands for lung and stomach studies. The result would be that the person involved would receive relatively high doses of radiation which in extreme cases, due to the increase in the dose as the square of the distance, would be 100 times (!) more than the amount that the subject would be receiving. /77

For all these reasons, the fluoroscopic device should only be used to check the correct position of the kymograph, although detail may be lost during fluoroscopy and the adaptation in such complicated tests could not be maintained.

The admissible radiation dose for the doctor and the personnel assisting him, working on x-ray studies, according to UVV 1953 can only be a maximum of 0.5 r/week.

These limiting values are understood to be a legal prescription for the personnel who help professionals working in the health service and welfare work, as well as regular blood picture checks related to possible radiation injury.

Determinations of scattered radiation dosage can be carried out approximately with the dental film method according to Bauer and Vogler, to determine the amount of radiation reaching the personnel. Better still is a constant monitoring of the personnel radiation dose by radiation badges (Work Group for Radiation Protection, Erlangen Medical University Clinic).

In such studies, there should be no neglect of protection against electrical accidents. The author, in the course of taking more than 1,500 pictures, only once suffered a harmless electrical shock from the standing bath apparatus, when someone forgot to ground it. One must be quite clear regarding the fact that the use of alternating current at 220 V in wet areas, and even more so in a submersible box, where it may easily happen that auxilliary personnel might have one hand on the kymograph housing and the other in the water or on the wet subject, constitutes an electrical source of danger of the first magnitude, if corresponding safety measures have not been taken. The advisability of such measures can be evaluated only by a trained electrical expert, who must be acquainted with the nature of the tests by witnessing them. It is no problem for such an individual to ensure absolute safety.

4. Previous Results

In the following tables we have summarized the results of these studies, to the extent that this is possible without providing illustrations. Another part of the changes that were observed can be understood only in the light of a larger number of illustrations, e.g., the change in shape of the individual kymograph curves which appear under hydrostatic pressure changes. Some illustrations have already been published (Ekert, Neumaier, Knoelle, Valet, de Cillia). A systematic compilation of kymogram forms which occur under hydrostatic and thermal effects on the body, will be found (to the extent that they are desirable for evaluating the individual kymogram symptoms in x-ray diagnostic areas) elsewhere with a greater number of illustrations.

Under hydrostatic and thermal effects in baths, the following kymogram symptoms were observed (the second and third rubrics indicate whether these symptoms also occur in healthy and sick persons for other reasons).

TABLE 1 /78

	Occurring in Healthy Persons Without Hydrostatic Effects	Occurring in Sick Persons
1. Motion deficiency at the lower left heart outline.	Movement + Type II	++
2. Cessation of movement at the lower left heart outline. Gaps in movement.	Very rare	++
3. Cava phenomenon, i.e., propagation and ventricular pulsation in the vena cava.	0	++
4. Spreading of the heart shadow in the diastolic position.	0	++
5. Changing of the heart shadow mostly in the mitral direction.	0	++
6. Pronounced protrusion of the atrial outline at the right.	0	++
7. Increased pulsation of the atrial contour at the right.	+	+

TABLE 1 (CONTINUED)

	Occurring in Healthy Persons Without Hydrostatic Effects	Occurring in Sick Persons
8. Cessation of motion of the atrial contour at the right.	0	+
9. Lateral plateau formation at the area of the apex of the heart.	Rare	+
10. Medial plateau formation in the area of the apex of the heart.	Very rare	+
11. Systolic lateral movement in the area of the apex of the heart.	0	+
12. Splitting of the movement in the area of the apex of the heart.	Very rare	+
13. Bend to the left in the contour.	Very rare	Very rare
14. Bright triangle beneath the elevated apex of the heart.	Rare	Rare
15. Strong changes in the movement type or hilar vessels.	/	+
16. Enlargement of the movement amplitude of the pulmonalis arc in comparison to the behavior of the aortal node.	0	+
17. The right pressure of the heart.	0	0
18. Slope of the aortal node lateral movement.	0	+
19. Amplitude reduction in the area of the aortal node.	0	+
20. Amplified incisura of the aortal medial movement.	+	+
21. Changes in size, shape and position of the gastric vesicle.	/	/
22. Change in the nature of representation of the entrainment of the lungs.	0	+
23. Reduction of the size of the heart shadow.	/	/

While the symptoms listed under 1-8 are clearly evident, those such as /79
lateral or medial plateau formation, systolic lateral movement, splitting, bends in the contour and sloping of lateral movement require explanation. This

involves a change in the individual marginal movement notches occurring in pulsation in the area of the ventricular action. These notches show regular pointed-hook shapes. If the tips of these notches are flattened laterally, we speak of lateral plateau formation; if the medial end of the movement is wide instead of pointed, we speak of medial plateau formation. A systolic lateral movement then occurs if, during systole, in other words, when the edge of the heart actually must move medially, a lateral movement can be observed. This situation can arise in the area of the apex of the heart by virtue of the fact that the upper parts of the left ventricle contract so sharply that a lateral compensating movement of the ventricular wall occurs in the lower segments. This symptom, however, may have to do with the nature of the marginal movement as an interference curve; the marginal movement is admittedly produced not only by pulsation but also, as we have already mentioned, possibly by other movements, for example a retrograde movement of the entire heart toward the left, an eccentric rotary movement (weather flag shadow phenomenon and so forth). The splitting consists in a breaking up of the pointed hook shape into a plurality of movements, where in addition to the factors mentioned, reflux waves may be involved. The bend in the contour consists only in the formation of a bending angle at the left ventricular contour, probably created by the fact that during rapid ventricular filling the pericardium in the lowest segment undergoes somewhat of a flattening of its roundness by virtue of its pressure against the diaphragm. The changes in the movement in the aortal node may be of the same origin as those in ventricular movement. Another item of significance in this context is the sloping of the lateral movement, which indicates difficulty with flow toward the periphery and can otherwise be observed, for example, in aortal stenoses.

The following table is particularly interesting from the balneotherapeutic standpoint; it shows the differences with respect to heart shadow size, the cardiac vessel band shape and its marginal movement type in the individual applications. Particularly noteworthy is the fact that on the one hand the absent hydrostatic pressure, as for example in rising arm baths, in foam baths and so forth, the number of symptoms decreased, likewise high temperature, while the CO_2 bath — this was an artificial one — with indifferent temperature did not reduce the symptoms at all, but increased them instead, so naturally from the therapeutic standpoint we can merely conclude that even in these baths we must anticipate a stronger effect of the hydrostatic pressure and movement of the blood mass toward the periphery during the application apparently does not occur. The fact that absence of the sudden filling symptoms in the full bath, also to some extent a relief of the pressure toward the periphery, is not always therapeutically significant, on the other hand, is shown by the hot full bath, which undoubtedly remains a load on the circulation.

Series I and V were performed by Blakkolb, Series II by Knoelle, Series III by Ritter, Series IV by Fink, Series VI and VII by de Cillia, Series VIII and IX by Valet, Series XI by Anstett and Series XII by Epple, for which however still an older, forgotten work is available. The entire body of material was looked over in detail once more by Ekert and Haakh, and revised after new viewpoints and other limitations had cropped up in the course of the studies. Kymographic investigations before and after therapeutic baths were published by Neumaier. They are not contained in the following table.

The important result of the comprehensive (but incomplete, and not continued /81 by us due to change in position) research studies it should be pointed out that with a simple full bath and with diverse therapeutic full baths, at least in certain breathing positions, to be precise, those which were recorded in the available studies by means of x-ray kymographs, showed spreading and deformation of the heart and vascular band shadow that could be detected by means of x-rays as well as considerable changes in the movements of the margin of the heart, which could be viewed partially as an expression of a strong filling with blood due to the action of hydrostatic pressure. In a number of the observed symptoms one could even speak of a "sudden filling symptom", an expression that anticipates nothing about the clinical and therapeutic evaluation. These symptoms do not always occur, but seem to be determined by constitutional and other factors; when the hydrostatic pressure rises, for example in a standing bath the depth of a man, they are more frequent and pronounced.

TABLE 2. COMPARATIVE TABLE ON THE FREQUENT CHANGES IN X-RAY KYMOGRAMS OF THE HEART AND THE VASCULAR BAND IN INDIFFERENT AND THERAPEUTIC TUB AND PARTIAL BATHS AFTER THE WORK OF THE AUTHOR AND HIS ASSOCIATES IN 1936-1943.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Number of Cases (Total of 160)	16	24	7	14	8	8	14	11	20	10	16	12
Changes in the Heart Kymogram with Average Depth of Inspiration	Indifferent Tub Full Bath, Normal Tub	CO_2 Tub Full Bath, Indifferent Temperature	Hot Tub Full Bath Without Additions	Hot Foam Tub Full Bath	Hot Tub Full Bath with Extropin Added	Mud Tub Full Bath, Thick Consistency, 41°	Mud Tub Full Bath, Thin Consistency	Standing Bath up to the Navel, Indifferent Temperature	Standing Bath up to the Jugular, Indifferent Temperature,	Indifferent Tub Full Bath in Old Steep Tub	Indifferent Tub Full Bath (in Experimental) Flat Tub	Increasing Partial Baths
1. Deterioration of motion of the left lower heart contour (transition to Type II after Stumpf).	15:16	21:24	5:7	0	5:8	4:8	7:14	6:11	19:20		11:16	0
2. Cessation of motion of the lower left heart contour as well as gaps in the motion at the typical point.	5:16	6:24	0	0	1:8	2:8	3:14	1:11	8:20		2:16	0
3. Lateral plateau formation of the notches in the vicinity of the apex of the heart.	1:16	1:24	0	0	1:8	-	-	1:11	20:20		9:16	0
4. Systolic lateral movement in the area of the apex of the heart.	8:16	11:24	0	0	3:8	3:8	7:14	1:11	7:20		9:16	0
5. Splitting of the notches in the area of the apex of the heart.	5:16	10:24	3:7	1:14	2:8	2:8	5:14	1:11	10:20		9:16	0
6. Cava phenomenon, i.e., broadening and abnormal ventricular pulsation of the vena cava superiora.	14:16	18:24	3:7	0	5:8	6:8	11:14	2:11	20:20		9:16 slight	0
7. Spreading of the heart shadow.	7:16	15:24	2:7	0	2:8	2:8	7:14	8:11	18:20		3:16	0
8. Narrowing of the heart shadow.	0	0	0	6:14	0	0	0	0	0		1:16	12:12 9:12
9. Severe deformation of the heart shadow.	5:16	5:24	0	0	0	3:8	7:14	1:11	19:20		10:16	0
10. Bright triangle beneath the apex of the heart.	1:16	11:24	0	0	1:8	1:8	1:14	0	5:20		0	

Note: The other phenomena were observed only in individual cases or with shortness of the notched stretches in flat kymograms merely indicated and numerically not reliably observed, as for example the frequent sloping of the lateral movement of the aorta.

The observed changes are not without interest from the circulatory physiological standpoint and provide a basis for further work, including that in the field of cardiac pharmacology. Under certain conditions, they take on a certain degree of significance for practical balneotherapy, but this requires checking, mostly because in the case of patients such pictures must be made before beginning of a bath cure and an attempt made to determine whether certain forms of reaction to bath therapy react in a certain fashion or whether the arrangement of certain water levels, the manner of sitting in the tub and so forth are of significance. Such studies can be carried out at relatively low cost once the apparatus has been obtained and would lead to understanding on the part of the patient as well, since the method used for subjects would not have to be carried out completely.

X-ray cinematographic studies would be very promising during the use of baths; however, this is very difficult from the technical standpoint and constitutes radiation danger without image converters. For a more detailed analysis of the movements of particular points, the heart shadow margin and so forth, the Heckmann electrokymographic method could be used, but we have no experience with this ourselves.

Summary

The article is a survey of the techniques, the necessary apparatus, experience gained thus far and future possibilities of the development of x-ray kymographic studies of the central circulatory organs during exposure to the action of simple and therapeutic full baths, partial baths and flat bathtubs as well as in experimental standing baths the depth of a man. The method involves changes in the heart and vascular band shadow size, the shape of these organs and their marginal movements. There seem to be some marked differences between the various applications, also with respect to the size and shape of the heart /82
vessel band shadow during the application, which primarily can be linked to the different hydrostatic pressure and temperature effects and partially perhaps as

the consequence of sudden filling states. In the opinion of the author, it would perhaps be very valuable to continue these studies systematically using newly developed x-ray technological devices, possibly with x-ray cinematographic controls which would make it possible, despite the radiation exposure, to use them after further modification of the electronoptical image converter. Brief mention is made of the relationship between such studies, which are used primarily for balneotherapeutic purposes, and circulatory physiology, x-ray diagnosis and other fields.

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Further pertinent literature citations in the cited works will be found in particular in Anstett, Blakkolb and Groedel.

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